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NEW PROVISIONAL APPLICATION TRANSMITTAL LETTER

Sir:

Transmitted herewith for filing is the Provisional Patent Application of Inventor(s):

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For: Transceiver Supporting Multiple Applications

Enclosed are the following papers required to obtain a filing date under 37 C.F.R. §1.53(c):

0 Sheets of Informal Drawings
5 Pages of Specification, Drawings & Tables
0 Claims

The following papers, if indicated by an ☒, are also enclosed:

☐ A Declaration and Power of Attorney
☐ An Assignment of the invention
☐ An Information-Disclosure Statement, Form PTO-1449 and a copy of each cited reference
☐ A Small-Entity Declaration
☒ A Certificate of Express Mailing, Express Mail Label No. EE810799905US

Basic Fee: $150

☒ A check in the amount of $150 is enclosed to cover the Filing Fee.

Please address all communications and telephone calls to the undersigned.

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PATENT
103118-0060

UNITED STATES PROVISIONAL PATENT APPLICATION

of

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for a

A METHOD FOR RANDOMIZING THE PHASE OF THE CARRIERS IN A MULTICARRIER COMMUNICATIONS SYSTEMS TO REDUCE THE PEAK TO AVERAGE POWER RATIO OF THE TRANSMITTED SIGNAL

A Method for Randomizing the Phase of the Carriers in a Multicarrier Communications Systems to Reduce the Peak to Average Power Ratio of the Transmitted Signal

By

Marcos Tzannes

Background of the invention

Discrete Multi-Tone (DMT) modems (a.k.a. multicarrier modems) transmit multiple individually modulated tones in parallel. The DMT transmitter is typically implemented by using an Inverse Fast Fourier Transform (IFFT) to generate the modulated waveforms (Figure 1). The resulting transmitted time domain signal, which is the linear combination of multiple modulated tones (carriers), can be approximated to have a Gaussian probability distribution. This approximation is accurate if the phase of the modulated tones is truly random. Since phase modulation is used to modulate signals in DMT systems, this implies that the transmitted data bits must be random as well. Most DMT transmitters use data scramblers for this reason. The scrambler, which is positioned before the IFFT modulator, will output data bits that are randomized in order to assure that the transmitted signal at the output of the IFFT modulator will have a Gaussian probability distribution. Generating a transmitted signal with a Gaussian distribution is important in order to transmit a signal with a low Peak to Average Power Ratio (PAR). The PAR of a signal is an important aspect of a system design because it effects the total power consumption and component linearity requirements of the system.

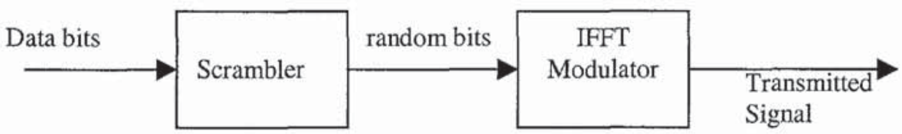

Figure 1: DMT modulator

The problem with DMT transmitters that operate in such a manner is the inherent assumption that the phase of the modulated carriers is random. If for any reason the phase of the modulated carriers is not random then the PAR can increase greatly resulting in system with high power consumption and/or with high probability of clipping the transmitted signal. Examples of cases where the phases of the modulated carriers are not random are when:

1) scramblers are not used
2) multiple tones are used to modulate the same data bits
3) the constellation maps (mapping of data bits to tone phases) used for modulation are not random enough.

There are obviously other cases where the phase of the IFFT carriers may not be random enough to generate a "Gaussian distributed" transmitted signal. This invention provides a mechanism to randomize the phase of DMT tones for the three examples above, as well as for other cases not specified in this invention which require such randomization to decrease the PAR of the transmitted signal.

Overview of the invention

This invention describes a method for randomizing the phase of DMT carriers in order to reduce the PAR of the transmitted signal. The phase randomization is important in cases where several modulated carriers may have the same phase. As mentioned in the previous section, examples of when this would occur are:

1. The data bits being modulated are not truly random. This could occur, for example, if a scrambler is not being used and the data bits have a specific repetitive pattern (e.g. all zeros, or all ones)
2. The same data bits are used to modulate multiple carriers. This would occur in cases where it was desired (or required) to send the same data bits on different carriers and then combine the results at the receiver in order to receive the bits at a lower Bit Error Rate (this is a well-known method for using frequency diversity to decrease the BER).
3. Constellation maps do not provide a truly random phase mapping. Constellation maps are used map data bits to DMT carrier phases. An example of a commonly used constellation map is shown in table 1. This one bit constellation map will provide some randomness to the phase of the DMT tones, but this randomness is limited since there are only two possible phase states.

Data Bits	Phase of DMT carrier
0	90 degrees
1	-90 degrees

Table 1: one bit constellation map

For the conditions mentioned above, and other conditions where the DMT carrier phases are not sufficiently random, this invention describes how to efficiently randomize the phase of the modulated carriers in order to provide a low PAR in the transmitted signal.

The method for randomizing the phase of these tones is as follows:

The phase of each DMT carrier is randomized by adding a different phase shift to each DMT carrier. This phase shift is based on a variable that is known in advance by the DMT transmitter and the receiver. This variable is not related to the data bits so that it is independent of the randomness of the data bits. Examples of such variables are the DMT carrier number, the DMT symbol (or frame) count (or superframe count), etc.
DMT carrier number: DMT systems enumerate the carriers in ascending order in frequency. The DMT carrier number represents the location of a tone in frequency relative to other tones. As an example, in DMT ADSL systems there are 256 DMT carriers, separated by 4.3125 kHz, spanning the frequency bandwidth from 0 kHz to 1104 kHz. DMT carriers are numbered from 0 to 255. As an example, "DMT carrier number 50" represents the 50th DMT carrier located at the frequency position 50*4.3125=215.625 kHz.
DMT symbol count: DMT systems often use DMT symbol (or frame) counters to synchronize the data transmitted between the transmitter and the receiver. DMT symbol counters are used to number DMT symbols in time as they are transmitted and received by DMT systems. In DMT ADSL systems there is a symbol counter called a "frame counter" that is synchronized between the transmitter and the receiver that is based on a module 68 count. This means the ADSL DMT symbol count (frame count) counts from 0 to 68 and then repeats again from 0 to 68 and so on. The collection of 69 consecutive DMT frames is called a "DMT superframe" in ADSL systems. There is also an ADSL DMT "superframe counter" that is synchronized between the transmitter and the receiver that is based on a module 255 count of DMT superframes. This means the ADSL DMT superframe count counts superframes from 0 to 255 and then repeats again from 0 to 255 and so on.

In this invention, the phases of DMT carriers are randomized by adding different phases shifts to the DMT carriers based on variables such as the DMT carrier number and DMT symbol count. The invention uses

equations that may contain one or several of these variables. As examples, the phase of a carrier could be randomized by adding a different phase shift to each carrier that is based on the following equations:

Example 1: (Phase shift added to carrier number N) = N*π/3, modulo 2π. In this example, carrier number N=50 would have a phase shift added to the modulated carrier that is equal to 50*π/3 (modulo 2π) = 2/3π. Carrier number N=51 would have a phase shift added to the modulated carrier that is equal to 51*π/3 (modulo 2π) = π. And so on.

Example 2: (Phase shift added to carrier number N)= (N+M)*π/4, modulo 2π where M is the symbol count. In this example, carrier number N=50 on DMT symbol count M=8 would have a phase shift added to the modulated carrier that is equal to (50+8)* π/4 (modulo 2π) = π/2. Carrier number N=50 on the next DMT symbol count M=9 would have a phase shift added to the modulated carrier that is equal to (50+9)* π/4 (modulo 2π) = 3π/4.

Example 3: (Phase shift added to carrier number N)= X_N * π/6, module 2π, where X_N is an array of N pseudo-random numbers. In this example, carrier number N=5 and X_N = [3, 8, 1, 4, 9, 5, …] would have a phase shift added to the modulated carrier that is equal to (5+9)* π/6=π/3. Carrier number N=6 would have a phase shift added to the modulated carrier that is equal to (5+5)* π/6=5π/3.

Obviously other equations are possible using other variables that are synchronized and known by both the transmitter and receiver. Obviously other constructions of equations are also possible. The fundamental principle used in this invention is to use known parameters at the transmitter and the receiver to randomize the phase of the tones in a multicarrier system. By using known parameters that vary over frequency (such as the DMT tone number) or over time (such as the symbol count) to randomize the phase of all the carriers transmitted DMT symbol, the transmitter and receiver can easily process the data without regard to the information data bit content. This invention has many advantages including the reduction of the PAR of the transmitted signal when the data bits being modulated are not random. As a result, another advantage of this invention is that it allows elimination of the data bit scrambler in DMT systems.

In another embodiment of this invention, the phase scrambling is used as a method to avoid clipping of the transmitted DMT signal on a symbol by symbol basis. In this embodiment, if a particular DMT symbol clips in the time domain (i.e. one or more time domain samples are larger than the maximum allowed digital value), the transmitter sends a predefined signal in place of the clipped DMT transmitted signal. The predefined signal is the same duration in time as a DMT symbol and can be treated by the transmitter and the receiver as a DMT symbol as such. It simply is not based on the modulated information bits and can be easily detected by the receiver. When the receiver detects the predefined signal it just discards it.
In this embodiment the phase of the DMT carriers are scrambled based on a parameter that varies over time (e.g. the symbol counter). As a result, at the transmitter the same information bits modulated in the DMT symbol following the clipped DMT symbol will produce a different time domain signal. The new DMT symbol will have a different phase randomization than the clipped DMT symbol because the phase of the DMT tones will have changed since the phase randomization parameters change over time. As a result, since clipping occurs infrequently, the new DMT symbol will most likely not clip as well. In the unlikely event the new DMT symbol does clip then once again the same predefined signal is sent by the transmitter instead of the clipped DMT symbol. This process continues until a DMT symbol that is not clipped is generated and sent. The probability of a DMT signal clipping in time depends on the PAR of the signal.
In general, DMT systems are designed to clip very infrequently, e.g. on the order of 1 clip every 1E7 time domain samples. Therefore it is very unlikely that consecutive DMT symbols that are phase randomized according to this invention will clip. If they do though, as described above, the system simply sends another version of the predefined signal and tries again to generate a non-clipped signal during the next DMT symbol period. The receiver simply looks for the predefined signal in every received DMT symbol period. If it detects that predefined signal pattern, the receiver discards the received DMT symbol. If it does not detect the signal predefined pattern it demodulates the received DMT symbol using the phase randomization information for that specific instance in time.

As mentioned above the predefined signal has the same duration as a DMT symbol in order to maintain symbol timing between transmitter and receiver. Obviously the predefined transmitted signal can be a variety of different signals. It can be a known pseudo-random sequence pattern that is easily detected by the receiver. It can also be an "all zeros" signal, i.e. a zero voltage signal at the transmitter output (zero volts modulated on all the carriers). This can also be easily detected by the receiver. This also has the advantage that it greatly reduces the power consumption of the transmitter when this zero volt signal being transmitted. Obviously any other predefined, easily detected signal can be used as well.
One important point to note is that in case where a pilot tone is used for timing recovery the predefined signal may contain a pilot tone in order to maintain sample phase lock during reception of the predefined signal.

As specific example of this embodiment of the invention consider the case where the following equation is used to randomize the phase of each DMT carrier:

Phase of carrier # N = $(\pi/3)*(M+N)$, where N is the DMT carrier number and M is the DMT symbol count.

If on DMT symbol count M=5 the DMT symbol clipped in the time domain then the "all zeros" signal is sent instead of the current clipped DMT symbol. On the following DMT symbol period, DMT symbol count M=6 is used in the phase randomizing equation generating a different time domain signal. If this new signal is not clipped then the DMT symbol is transmitted. If this new signal is clipped then the DMT symbol is not transmitted and the "all zeros" signal is sent instead. The algorithm is continued in this manner so that only signals without clipping are transmitted.
Another benefit of this embodiment of the invention is that it allows DMT systems to be designed with a lower PAR. In general DMT systems are designed to have a large PAR, on the order of 14.5 dB. This will result in a 1E-7 clipping probability for the time domain signal. The penalty of a high PAR is that it requires the implementation of an analog front end with higher power consumption and analog components with higher voltage linearity requirements.
This invention allows the design of DMT systems with lower PAR because in the event a DMT symbol clips, the predefined signal is sent instead. As a result the DMT systems can relax the strict 1E-7 probability of clipping requirement and lower the PAR. As an example the system could operate with a 1E-5 probability of clipping (PAR=12.8 dB). Assuming a DMT symbol had 512 time domain samples this would result in one clipped DMT symbol out every 100000/512= 195 DMT symbols. Therefore 1 out of 195 or approximately 0.5% of the time the predefined signal would be sent instead of the clipped DMT symbol. This 1.7 dB reduction in PAR will result in large savings in transmitter complexity in the form of power consumption and component linearity.